Exhibit A

30 years, as well as for glass polishing and for bonded silicon-on-insulator (SOI) wafers. Although its application to ILD planarization is more recent, both the equipment and the technique are well known to the semiconductor industry.

The requirements and the process for polishing a dielectric are quite different from those for polishing Si. For dielectric polishing, the goal is to remove topography and yet maintain good uniformity across the entire wafer. The amount of material removed is about 0.5 to 1 μm, compared to Si polishing where several tens of micrometers of material are removed. The uniformity requirement for ILD polishing is much more stringent than for Si polishing, since nonuniform ILD films lead to window etching and plug formation difficulties. Consequently, even with more than 30 years of experience in Si wafer polishing, the industry found that new processes and new equipment had to be developed for ILD polishing. Recently, CMP has been applied to polishing metal for W plug formation and embedded metal structures. Metal polishing involves chemistries significantly different from those for oxide polishing and requires further research and development.

The schematic of the CMP equipment is shown in Fig. 39. The essence of a CMP process is an automated rotating polishing platen and a wafer holder, which can both exert a force on the wafer and rotate the wafer independent of the rotation of the platen. The polishing is accomplished by a polishing slurry consisting of colloidal silica suspended in a KOH solution. An automatic slurry feeding system is used to ensure the uniform wetting of the polishing pad and the proper delivery and recovery of polishing slurry. For a unit designed for industrial use, automatic wafer loading and a cassette-to-cassette handler are also incorporated.

The basic polishing mechanism for an SiO_2 dielectric is the same as for glass polishing and has been summarized recently.[155,156] The mechanical removal rate of the glass is given by the Preston equation,[157]

$$R = K_p p v \qquad (8.51)$$

where R = rate of removal
p = applied pressure
v = relative velocity between the wafer and the polishing pad
K_p = proportionality constant

K_p has units of $(\text{pressure})^{-1}$ and is known as the Preston coefficient. K_p is a function

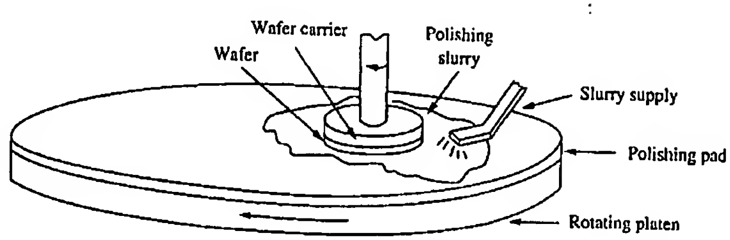

FIGURE 39
A schematic of a CMP polisher.

of the mechanical properties of the glass (hardness, Young's modulus), the polishing slurry, and the composition and the structure of the polishing pads.

Although Eq. (8.51) is essentially mechanical in nature, the microscopic action of polishing is both chemical and mechanical. The exact mechanism for polishing is still not fully understood. Figure 40 shows the current understanding of the chemical/mechanical events during polishing. The chemical reactions can be divided into four stages: (1) the formation of hydrogen bonds with the oxide surfaces of both the wafer and the slurry particles (hydroxylation), as in Fig. 40*a*; (2) the formation of hydrogen bonds between the wafer and the slurry (Fig. 40*b*); (3) the formation of molecular bonds between the wafer and the slurry (Fig. 40*c*); and (4) the breaking of the oxide bonds with the wafer (or the slurry) surface when the slurry particle moves away (Fig. 40*d*).

From the chemical/mechanical events shown in Fig. 40, there are three important implications: (1) Polishing is not a mechanical abrasion of slurry against the wafer surface; (2) both the presence of water and the pH of the solution affect the formation of hydrogen bonds; and (3) the size and the composition of the slurry particles are important. Relying on chemical/mechanical action rather than mechanical abrasion avoids a mechanically damaged surface layer on the ILD. The microscopic nature of CMP distinguishes it from mechanical abrasion, which is unacceptable to ULSI applications. Because of the chemical nature of bond breaking, the polishing slurry has a large effect on the polishing rate. The most commonly used slurry for SiO_2 polishing is silica with a particle size about 10 to 90 nm. In general, slurries made from oxides with higher oxygen bond strengths give higher polishing rates. The highest polishing rate achieved, with cerium oxide, is several times higher than that of silica.

Figure 41 illustrates the arrangement of a patterned wafer on a polishing pad. Instead of the wafer being held directly on the chuck, a backing film is sandwiched between the wafer and the chuck. The film provides elasticity between the chuck and the wafer. A composite set of two pads is used to achieve the desired rigidity/elasticity for polishing. Figure 42*a* illustrates the need for elasticity between the chuck and the wafer. Without a backing film any defect or particle on the chuck or on the back of the wafer will cause a thin spot. In addition, wafer breakage is more likely. If the polishing pad is too soft, as in Fig. 42*b*, then polishing is conformal to the wafer surface and no planarization is achieved. Planarization is caused by the capability of the polishing pad to bridge over low spots on the wafer and thus preferentially removing material from the high spots, as shown in Fig. 42*c*.

Therefore, microscopically, the removal of material in contact with the polishing pad is mainly chemical in nature. Planarization occurs because only high spots on the wafer touch the polishing pad. Because the macroscopic removal of material depends on the mechanical contact between the wafer and the polishing pad, the Preston equation [Eq. (8.51)] still applies well to CMP.

The detailed mechanism for planarization has not been fully elucidated and is an active field of research. A phenomenological model[158] using three parameters, corresponding to high features, low features, and horizontal erosion, is successful in simulating the erosion profiles of isolated and clustered features. Recently, a fluid model, which treats the slurry as a hydrodynamic layer, has been developed.[159] This

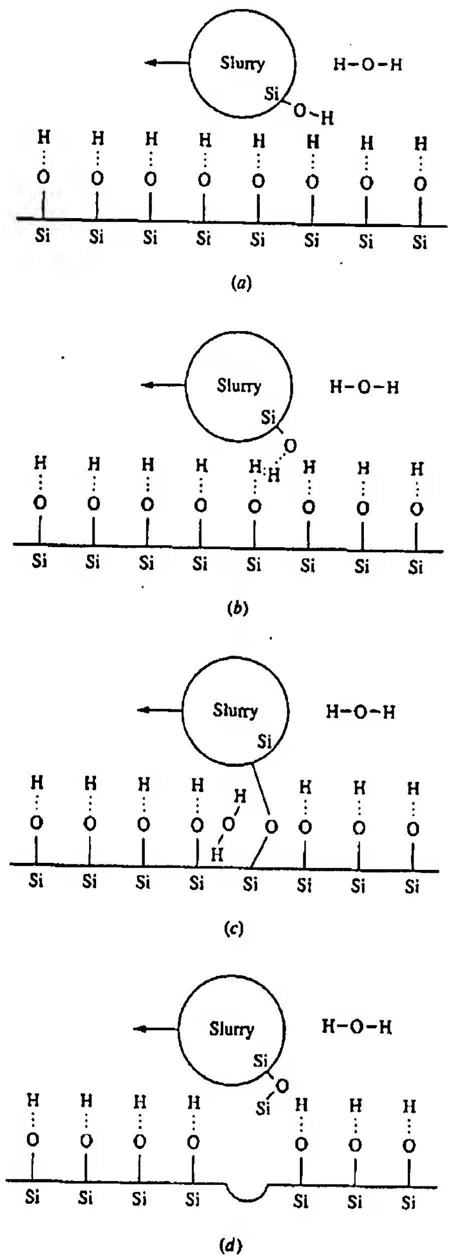

FIGURE 40
The mechanism of chemical/mechanical polishing: (*a*) In aqueous solution oxide forms hydroxyls; (*b*) hydrogen bond is formed between the slurry particle and the wafer; (*c*) Si–O bonds are formed by releasing a water molecule; (*d*) the Si–Si bond breaks when the slurry particle moves away.

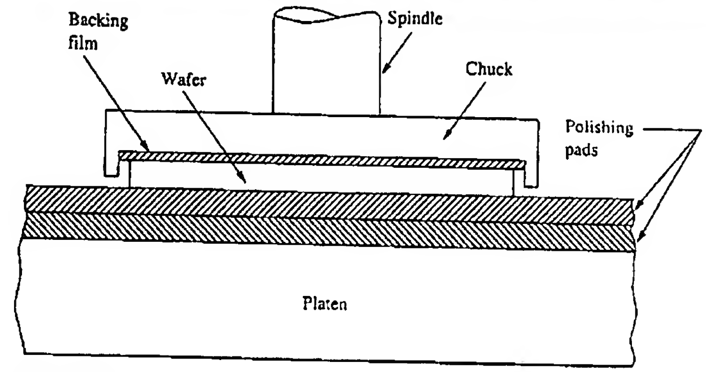

FIGURE 41
Details of the CMP wafer carrier and polishing pads.

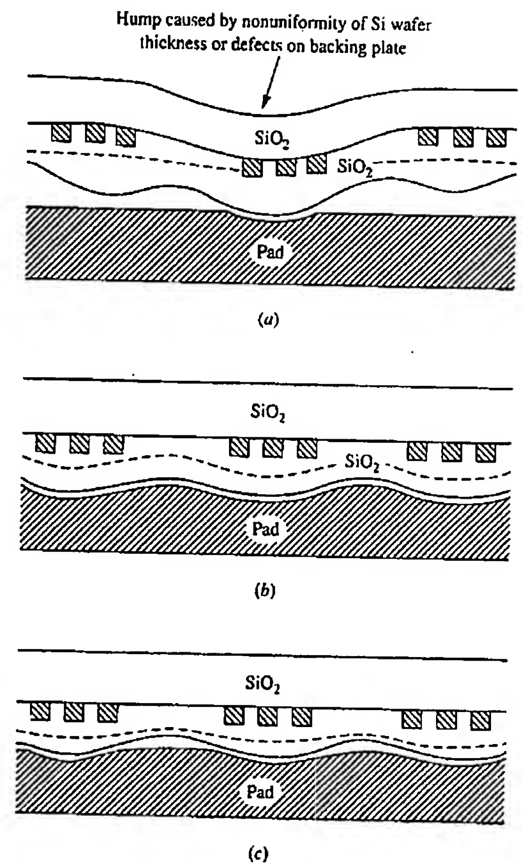

FIGURE 42
The effect of rigidity of the backing chuck (film) and the polishing pad: (*a*) A rigid chuck may bend the wafer and cause a thin spot; (*b*) a soft pad conforms to the surface and does not planarize; (*c*) a moderately rigid pad polishes the high spot on the wafer. The dashed lines show the final polished profile.